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RESEARCH

Status of Fire Boom Performance Testing

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Most response plans for in situ burning of oil at sea call for the use of a tire-resistant boom to contain the oil during a burn. Presently, there is no standard method for the user of a tire-resistant boom to evaluate the anticipated performance of different booms. The American Society for Testing and Materials (ASTM) F-20 Committee has developed a draft Standard Guide for In *Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom; however, the draft provides only general guidelines and doec not specify the details of the test procedure. Significant advances have been made in the past three years in implementing the guidelines in the draft standard. Two series of tests, one using diesel fuel and one using propane, have been conducted to evaluate the protocol for testing the ability of fire-resistant booms to withstand both fire and waves. A brief description and comparison of these tests is presented along with a discussion of the strengths and weaknesses of the use of each fuel and some issues identified in the tcsts.
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Introduction

In situ burning of spilled oil has distinct advantages over other countermeasures. It offers tlic potential to convert large quantities of oil into its primary combustion products, carbon dioxide and water. with a small percentage of smoke particulate and other unhurncd and residue byproducts. *In situ* burning requires minimal equipment and less labor than other techniques. It can be applied in areas where many other methods cannot be used due to lack of a response infrastruclurc and/or lack of alternatives. Because the oil is mainly converted to airborne products of combustion by burning, the need for physical collection. storage. and ti-ansport of recovered fluids is reduced lo the few pcrcenl of the original spill volume that remains as residue after burning.

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Oil spills on water naturally spread to a thickness where the oil cannot be ignited or burning sustained. It has been found that a minimum oil thickness of 1 5 mm is required for ignition depending on the nature of the oil (Buist *et al.*, 1994). As a result. the scenarios, which have been developed for hi *situ* burning of oil on water. include some means for corralling tlic oil. The use of fire-resistant containment boom is tlic method most often proposed for maintaining adequate oil thickness to support burning. In that scenario. oil is collected from the spill in a horseshoe or catenary-shaped boom towed by two vessels. Once an adequate quantity of oil has been collected from the spill. the oil is ignited and burned while being towed in the boom. The oil is maintained at a sufficient thickness in *the* apex of the boom to support burning until nearly all of the oil is consumed. The process of collecting and burning can then he repeated. For this scenario to bc successful. the boom must be capable of withstanding repeated lire exposures while containing the oil.

Background

Oil spill planners and responders need to know the expected performance of fire-resistant oil spill containment boom. This need has been addressed through either at-sea demonstration tests, tests in a pan or tank with static water, or tests in a wave tank. The focus of this presentation is on fire performance and not the oil collection performance. Methods for evaluating the oil collection performance have been reported previously (Bitting & Coyne, 1997).

Ideally, a test method should provide a measure of performance of the item being tested. The measure should be related in one or more ways to the anticipated use of the item. One method is a test, which replicates as closely as possible actual use conditions. This method is perhaps the easiest to understand and most commonly considered, but lacks flexibility. Unless there is a single use condition, a number of test conditions may be required to replicate all possible uses. A second method is a test, which measures properties of the item. If the relationship between the properties and the use conditions is known, the performance under a variety of conditions could be predicted.

Two important aspects of a test method are repeatability and reproducibility. Repeatability is the ability to obtain acceptably similar test results for the same item at a given location. Reproducibility is the ability to obtain acceptably similar test results for a given item at different test locations. Factors which affect repeatability and reproducibility are the control of test parameters and operator bias. Repeatability and reproducibility are often analyzed using statistical methods with a number of tests using multiple items and several test locations.

At the present time, there is not an adequate understanding to develop a test, which would relate boom component properties to the performance of a boom in actual use. Further, a component property test method would have to he compared with the performance of a complete boom to determine its ability to predict performance. This leads to the choice of a test, which replicates the conditions to which a fire-resistant oil spill containment boom would be exposed during the oil-burning phase of its deployment.

One candidate test method would be to deploy a boom at sea under prescribed conditions, corral a specified quantity of oil, burn the oil and observe the performance of the boom. While this procedure would most closely replicate actual use conditions, it would be very expensive and require environmental permits which are difficult to obtain in most areas. A few at-sea tests with fire-resistant oil spill containment boom have been conducted; most notably was the NOBE (Newfoundland Offshore Burn Experiment) burn in 1993.

Temporary oil containment areas in thick ice have been used in some countries to conduct oil spill research, hut the permits required in the United States appear to be the same as those for open waters. A related possibility would be to use actual oil spills or so-called "spills of opportunity." Fortunately, oil spills are fairly rare occurrences and the opportunity to conduct standardized tests, with a number of booms during a spill, would be an even rarer event.

This leaves a land-based containment tank as the best choice for the evaluation of the fire performance of a number of booms. There are a number of containment areas, pits, tanks or pans, which are designed and permitted for burning liquid fuels. Most of these are fire-training areas and some have been used in the past to evaluate fire-resistant booms. However, these do not have the capability to produce waves, which are considered an important aspect in evaluating fire-resistant boom. Wave tanks designed for oil spill research are generally not designed to withstand a fire and the environmental permits necessary for burning may be unavailable for these sites.

Design of Test Procedure

The ASTM F-20 Committee has developed a draft Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom. The draft standard could be considered a guideline since it does not provide all of the specific details necessary to conduct an evaluation of fire-resistant boom. It does, however, provide some general performance requirements related to the collection and burning of oil. Since it is a draft document under development, the standard continues to be revised. The principal burn related feature of the draft calls for a burn exposure, cool down cycle consisting of one hour of burning followed by one hour with no burning, followed by one hour of burning and one hour of no burning followed by one hour of burning. This is a total of 3 one-hour burn periods and 2 one-hour cool down periods. The wave characteristics to which the boom would be exposed during burning and cooling and the boom configuration were not specified.

Two principal approaches have been used in North America. One uses liquid fuel (diesel fuel) for the exposure fire and the other uses gaseous fuel (propane) for the exposure fire. The philosophy in developing these test procedures was to subject a boom to conditions, which could be used to evaluate the performance of the boom when used for *in situ* burning during a spill response. The ASTM draft standard served as guidelines in developing the procedures, but there also were environmental, engineering and economic constraints.

There are advantages associated with the use of either diesel fuel or propane. Diesel fuel fires closely represent crude oil fires in intensity: the boom material can absorb the fuel. and diesel fuel is relatively easy to transport and store. Propane fires produce little visible smoke. can be started and stopped quickly. the area of the fire can be easily controlled without containment. and there is no residue. Although propane appears to be the most attractive fuel, the principal disadvantage is the heat flux from a propane diffusion lire to the boom is about one half that from a large diesel fuel lire (Walton *et al.*, 1997). In order to generate a comparable heat flux with propane. air must hc added to the flames.

Diesel Fuel Tests

Fire boom test evaluations using diesel fuel wcre conducted in 1907 and 1998 by the National Institute of Standards and Technology (NIST), and sponsored by the US Coast Guard Research and Development Center and the US Minerals Management Service. Technology Assessment end Research Branch. The test evaluations were conducted in a wave tank designed specifically for evaluating fire-resistant boom located at the US Coast Guard Fire and Safely Test Detachment facility on Little Sand Island in Mobile Bay, Alabama (Walton *et al.*, 1998). The wave tank was constructed of steel and was 1.5 m deep with two perimeter walls 1.2 m apart forming an inner and outer area of the tank. The inside dimensions of the inner area of tlie tank were 30.5 m by 9.1 m. The wave tank was designed to accommodate a nominal 15 m boom section forming a circle approximately 5 in in diameter-. The heat flux at the base of a liquid pool fire nnd tlic burning rate are Functions of the tire diameter. The heat flux and the burning rate increase with increasing tire diameter for small fires. Once the diameter reaches 5 in. the heat flux and bur-ning rate are nearly constant as the fire diameter increases. Thus. the tire within the boom containment would he large enough to represent the thermal exposure from a larger tire.

A suspended paddle wave maker was used to produce 0.3 m high waves with a period of 3–5 s at a water depth of 1.2 m. The wave energy was dissipated with a sloping beach at the end of the rank.

The boom was kept in position during the test by 6 boom constraints or stanchions. The stanchions were mounted vertically in a pattern forming a circle around the center of the tank either inside or outside the boom circle. If the stanchions were located outside the boom circle. cables were used to connect the boom to the stanchions.

The fuel used for the tests was number 2 diesel fuel. The fuel was stored in a storage tank and pumped to tlie boom circle via an underground piping system. The fuel entered the center of the tank under water and floated to the water surface.

Fig. 1 Diesel fuel test

Tests series wcre conducted in this tank in 1997 with 5 booms and in 1998 with 6 booms. A complete description of the 1997 tests can be found in reference (Walton *et al.*, 1998). A photograph of tlie wave tank with a burn in progress is shown in Fig. 1

Propane Fuel Tests

Fire boom test evaluations using propanc were conducted in 1996 and 1097 by SL Ross Environmental. Ltd. and sponsored by the Canadian Coast Guard and the US Minerals Management Service, Technology Assessment and Research Branch The propanc test evaluations were conducted in a wave tank located at the Canadian Hydraulic Centre. National Research Council of Canada in Ottawa. The wave tank was constructed of concrete and was 120 m long by 60 m wide by 3.3 m deep. A pneumatic wave maker at one end of the tank could be used to generate waves up to 0.6 m in height although waves 0.34 m high with a period of 2 s were used for tlie tests. The wave energy was dissipated with a sloping bench at the end of tlie tank.

In the 1996 tests, a section of boom 14.6 m long was placed in a catenary shape. The ends of the boom were secured with cables and the shape was maintained with a current created with water jets. In the 1997 tests. the section of boom was oriented in a line along the direction of wave travel and held in place with tensioning cables.

The fuel used for the tests was commercial propanc. Liquid propane from a storage tank was heated to create gaseous propane and piped to an underwater bubbling system. Flames wcre applied to both sides of the boom to simulate the exposure observed in the diesel fuel tests and the NOBE experiment where flames were observed on both sides of the booin at the

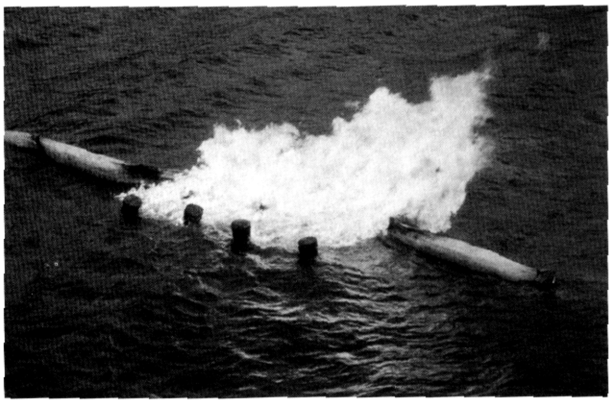

Fig. 2 Propane fuel test

apex. In the 1996 tests, propane alone was used. In the 1997 tests, compressed air was injected into the flames through nozzles around the boom. In the 1996 tests with propane only, the heat flux measured at the boom was substantially less than the beat flux measured at the boom in the diesel fuel fires. In the 1997 tests with air injected into the flames, the heat flux was comparable to that measured in the diesel fuel fires.

A complete description of the 1996 and 1997 tests can be found in references (McCourt *et al.*, 1997: McCourt *et al.*, 1998). A photograph of the wave tank with a burn in progress in the 1997 tests is shown in Fig. 2. Further tests with air-enhanced propane are planned for the fall of 1998 at OHMSETT, the National Oil Spill Response Test Facility. in New Jersey, which is operated by the Minerals Management Service.

General Observations

Although the diesel fuel and propane test development projects would appear to be in competition, this was not the case. There was significant cooperation on the part of the project engineers, which included the exchange of data and visits to both test sites. The diesel fuel tests appear to most closely replicate conditions expected during the actual use of *in situ* burning. The diesel fuel tests provided valuable data and experience in conducting tests and served as a benchmark for the propane tests. Test results have been submitted to the ASTM **F-20** Committee for use in developing the Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom. The tests also provided information to the boom manufacturers on the performance of their products.

In general, as would he expected, there was some degradation of materials in all of the booms with both fuels. Further, it appeared that many booms had not reached a steady-state condition in terms of degradation. That is, for many of the booms, if they had been subjected to further fire exposure, one would have expected further material degradation to take place. Since the principal purpose of these projects was to evaluate the test protocol, the booms were not rated as passing or failing.

Although two quite different methods of fuel delivery were used, the burn characteristics in both were influenced by the wind speed and direction. When the wind speed was low, the flames rose nearly vertically providing a relatively uniform thermal exposure to the boom. With increased wind speed, the most significant thermal exposure was observed to take place downwind of the flames. If the wind direction was relatively constant over the course of the three burns for a given boom, the same section of the boom received repeated thermal exposure. If the wind direction changed during the burns, differing sections of the boom received the most intense thermal exposure.

Issues and Conclusions

Overall, the test protocol and its application were considered successful with both diesel fuel and air-enhanced propane. The propane fuel test method appears promising for future use. particularly since very little visible smoke is produced. Based on the results of these tests, several issues have been identified for possible further consideration. These issues include the following items:

- Does the fire size and duration coupled with the wave action represent a realistic thermal and mechanical exposure? Although it is a largely subjective observation, the fire and wave exposures used in both the diesel fuel and propane tests appeared to provide a reasonable representation of the important features of actual in *situ* burn conditions. Presently, there are not adequate data available to compare the test performance to performance in an actual at-sea burn under given fire and wave conditions or compare the performance of all types of booms in the diesel fuel and propane tests.
- How does wind speed and direction affect the thermal exposure to the boom? The impact of the wind speed and direction on the thermal exposure are difficult to quantify. Heat flux measurements around the boom would provide the best measure of thermal exposure, but these are difficult to attach to the boom and a significant number would be required to adequately profile the thermal exposure along the length of the boom. It may be appropriate to impose a constraint on wind speed during a test.
- Should replicate tests he required? When evaluating a test method it usually is desirable to conduct mul-

tiple tests with the *same* product to determine if the method is repeatable. Production and prototype fire booms are expensive to manufacturer and the tests are expensive to conduct.

- What evaluation criteria should be applied to the booms at the end of the test? The criteria for evaluating a boom are one of the most difficult and sensitive issues. One option is to report the condition of the boom, including attributes such as freeboard, which can be measured. In some cases, holes in the booms above the waterline were noted and the impact of these holes on the expected performance of the boom was difficult to judge. Therefore, it is unlikely that a numerical rating could be developed for these tests so a pass or fail criteria may be the best option.

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